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Workshop Report On Astronomy Enabled By Ares V

Compiled and Edited by:

Stephanie Langhoff
Chief Scientist
Ames Research Center, Moffett Field, California

Dan Lester
Department of Astronomy
The University of Texas at Austin, Texas

Harley Thronson
Associate Director for Advanced Concepts and Planning
Astrophysics Division
NASA Goddard Space Flight Center, Greenbelt, Maryland

Randy Correll
Physicist
Ball AeroSpace, Boulder, Colorado

Report of a workshop
sponsored by and held at
NASA Ames Research Center
Moffett Field, California
on April 26-27, 2008

August 2008

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Table of Contents

Executive Summary

On April 26th and 27th, 2008, NASA Ames Research Center hosted a two-day weekend workshop entitled "Astronomy Enabled by Ares V." The primary goal of the workshop was to begin the process of bringing the Ares V designers together with senior representatives of the astronomical community to discuss the feasibility of using the Ares V heavy-lift launch vehicle, a major element in NASA's Constellation Program, to launch large observatories. Throughout the discussion we are referring to the Ares V design concept at the time that our workshop met. The design and even the name "Ares V" could change in the future. Key questions included:

(1) Are there telescope concepts or missions capable of breakthrough science that are either enabled or significantly enhanced by the capabilities of an Ares V?

(2) What demands do large telescopes place on the payload environment of the Ares V, such as mass, volume, fairing shape, cleanliness, acoustics, etc.?

(3) What technology and environmental issues need to be addressed to facilitate launching observatories on an Ares V?

(4) Is there a trade-off between mass and complexity that could reduce launch risk and, thereby, the cost of building large telescopes?

The workshop started with an overview of the Constellation program and the role of the Ares launch vehicles. It was made clear to the presenters that design changes in the Ares V cannot compromise its primary mission of transporting the Altair lander and supplies to the lunar surface. The large lift mass capability of Ares V (approximately 55 metric tons to Sun-Earth L2) and large fairing (8.8 meter interior diameter) opens up new telescope design possibilities that could significantly enhance the future of astronomy. Most of the concepts that were considered by the workshop are limited by volume, not mass, and many of the missions favored a "taller" fairing than the baseline design. The length of the fairing is constrained by the height of the Vehicle Assembly Building (VAB), although the current baseline length is shorter.

While an Ares V uniquely enables a few of the telescope concepts considered at the workshop, most have a baseline mission that can be flown on existing heavy-launch vehicles. However, the large fairing and lift capabilities of the Ares V open up new design concepts, e.g., large monolithic mirrors that reduce complexity and have no risk of deployment. The larger-aperture telescopes that can be launched on an Ares V offer much higher sensitivity and spatial resolution than telescopes that can be launched with current launch vehicles. This is particularly important for studies of the early Universe and for imaging exosolar planets.

While it is too early in the design cycle of the Ares V for a definitive understanding of its launch environment, designing to a launch environment comparable or better than the Shuttle was considered a good metric. Since the main engines can be throttled, it is expected that the acoustic and dynamic loads can be kept within acceptable limits.

One recurring theme that was not included in the workshop agenda was the importance of on-orbit servicing of astronomical observatories. The recent success of the Defense Advanced Research Projects Agency's (DARPA) Orbital Express has demonstrated that on-orbit servicing can be done autonomously if the telescopes are designed with standard servicing functions. For almost two decades, the Hubble Telescope servicing missions have dramatically increased the scientific value of the telescope by implementing improved instruments and detector technology. The Ares V and other Constellation assets could enable servicing of satellites either autonomously or with astronauts. It is precisely because Ares V can launch extremely large, capable, and expensive telescopes that on-orbit servicing to repair and upgrade those telescopes appears to add considerable value. This subject is futher discussed in section IV, and was proposed to be the subject of a follow-on workshop at Marshall Space Flight Center and supported by Goddard Space Flight Center, Johnson Space Center, and Ames Research Center.

The workshop clearly showed that the Ares V has considerable potential to do breakthrough astronomy. It is also likely that it could advance the Earth science and planetary science goals of NASA. A follow-on workshop on solar system science applications is being held at NASA Ames in August 2008. We intend the results of these workshops to be useful to the National Research Council's overall assessment of the science capabilities afforded by the Constellation Program.

Workshop Report On
Astronomy Enabled By Ares V

Stephanie Langhoff[1], Dan Lester[2], Harley Thronson[3], and Randy Correll[4]

Ames Research Center

I. Introduction

A workshop entitled "Astronomy Enabled by Ares V" was held at Ames Research Center on 26-27 April 2008. This workshop is part of a series of informal weekend workshops initiated and hosted by the Ames Center Director, Dr. Pete Worden. The organizing committee included Stephanie Langhoff (Chair), Gary Martin, and John Karcz of Ames Research Center; Greg Sullivan, Phil Stahl, and Kenneth Morris of Marshall Space Flight Center; Harley Thronson of Goddard Space Flight Center; Dan Lester of the University of Texas; and Marc Postman of the Space Telescope Science Institute. The workshop agenda was structured to bring together the Ares V designers and the science and engineering communities who have a common interest in launching large telescopes. Forty-eight persons representing government, industry, and academia attended (see list of attendees). This workshop directly addresses recommendation 7-1 in the Aldridge report (http://www.nasa.gov/pdf/60736main_M2M_report_small.pdf), which recommends that "NASA seeks routine input from the scientific community on exploration architectures to ensure that maximum use is made of existing assets and emerging capabilities."

The agenda blended three major themes: (1) How can elements of the Constellation program, and specifically, the planned Ares V heavy-launch vehicle, benefit the astronomical community by enabling the launch of telescopes that cannot be launched on existing vehicles, and how can the capabilities of an Ares V allow the astronomy community to augment designs, achieve lower risk, and perhaps lower cost on these missions? (2) What are some of the telescope concepts that either can be significantly enhanced or enabled by an Ares V launch vehicle? What constraints do these mission concepts place on the payload environment of the Ares V? And (3) Technology challenges that need to be addressed for launching and servicing large observatories. Presentations varied in length from 15-30 minutes. Ample time was provided for discussion.

The final afternoon was devoted to interactive discussions, organized around three specific questions: (1) What breakthrough science can be done with an Ares V? (2) Payload development: What are major technological and environmental issues? And (3) Is there value in simplicity? The program ended with a discussion of research priorities and follow-on actions.

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[1]NASA Ames Research Center, Moffett Field, California
[2]Department of Astronomy, The University of Texas at Austin, Texas
[3]Astrophysics Division, NASA Goddard Space Flight Center, Greenbelt, Maryland
[4]Ball AeroSpace, Boulder, Colorado

II. Ares V Capability and Constellation Overview

The workshop began with an overview of the Constellation Program by Steve Cook, Ares Project Manager. The discussion here attempts to capture some of the key points made in his presentation, and to set the stage for the science presentations that follow. More in depth and authoritative accounts of the rapidly unfolding Constellation and Ares programs exist on the web, for example, at http://www.nasa.gov/mission_pages/constellation/ares/aresV.html.

As of May 2008, NASA's mission contains six major elements: (1) Safely fly the Space Shuttle until 2010; (2) Complete the International Space Station; (3) develop a balanced program of science, exploration, and aeronautics; (4) develop and fly the Orion Crew Exploration Vehicle; (5) land on the Moon no later than 2020; and (6) promote international and commercial participation in exploration. The key focus of the Constellation Program is to deliver both cargo and humans to the lunar surface. At the same time, it has been increasingly recognized that such transport systems can straightforwardly access other interesting destinations such as Geosynchronous Earth Orbit (GEO), the Sun-Earth and Earth-Moon Lagrange (libration) points, and some asteroids.

One of the cornerstones in the Ares program is to build on a foundation of proven technologies to reduce risk. The Ares I, which is under development now, will have a payload capacity of 25.6 metric tons to Low Earth Orbit (LEO), comparable to that of the Shuttle. For comparison, the Ares V is estimated to have a payload capacity of 143.4 metric tons to LEO, considerably larger than the Saturn V. The Ares V will, therefore, provide lift capability that exceeds all previous vehicles and will clearly open up new opportunities for science and human exploration.

Briefly, the Ares I is being designed to carry the astronauts in the Orion Crew Exploration Vehicle (CEV) that sits just behind the crew escape module atop the stack. The upper stage uses an expendable Saturn J-2-derived engine (J-2X) that uses LOX/LH_2 propellant, and is mostly based on proven technologies. The first stage engine on the Ares I is derived from the current Shuttle Reusable Solid Rocket Motor Booster (RSRM/B). It uses the same propellant, cases and joints, booster deceleration motors, aft skirt and thrust vector control, and tumble motors as the Shuttle. The use of heritage parts when feasible combined with the use of modern electronics and composite materials should produce a highly dependable solid rocket booster, while reducing complexity, risk, and cost.

The elements in the Ares V heavy-lift vehicle assumed in this workshop are shown in figure 1. The payload fairing is being designed to carry the Altair Lunar Lander. One of the primary focuses of the workshop was to determine what demands launching large astronomical observatories might place on the size of the fairing. There may be some design flexibility in the fairing as long as it carries out its principal mission of transporting Altair to the lunar surface. Other elements of the Ares V shown in figure 1 include the Earth Departure Stage (EDS), a loiter skirt, an interstage, and then the core stage that is powered by five Delta IV derived RS-68 LOX/LH2 engines and two solid rocket boosters. The Ares V is being designed using many of the major components being developed for the Ares I. For example, the RS-68 engines, the first-stage 5-segment solid rocket boosters, the J-2X upper stage engine, and the instrument unit, will all have heritage on Ares I.

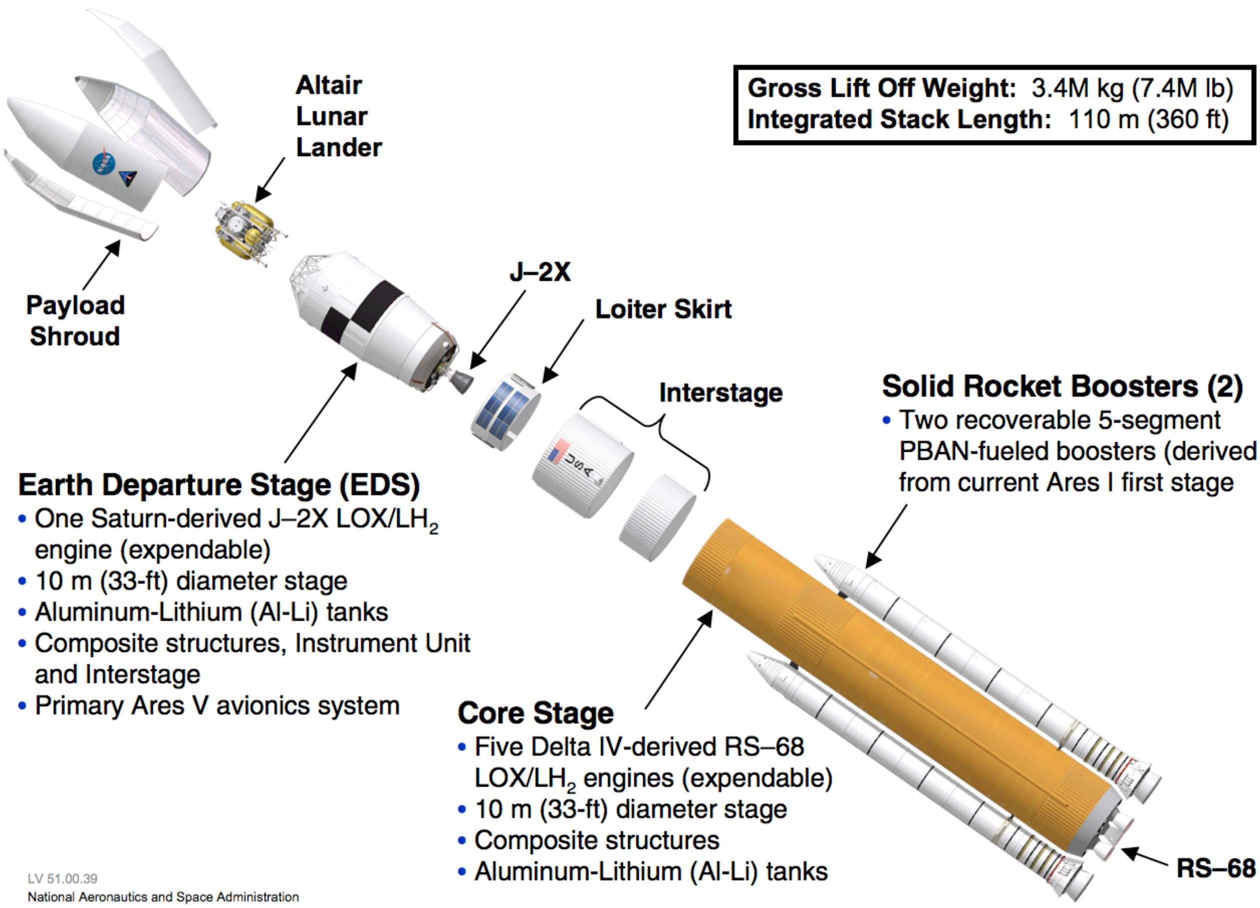

Figure 1. Ares V elements.

This should greatly reduce schedule and cost risks, as well as development and life-cycle costs. First test flights of the Ares I are scheduled to occur in April 2009, and the first test flight of Ares V is planned for 2017.

Overview of the Ares V Performance

Phil Sumrall, the Advanced Planning Manager for the Ares Projects Office, gave a two-part presentation on Ares V, providing first a mission and vehicle overview, and then a description of performance. Again, we emphasize that this is a current snapshot of an on-going program. A detailed comparison of vehicle size, payload capacity, and key components between the Space Shuttle, Ares I, Ares V, and Saturn V is shown in figure 2. The Ares V, which is primarily being designed as a heavy-launch vehicle to place cargo on the Moon, is intended to have greater payload capacity to Low Earth Orbit (LEO) (~143.4 metric tons (mT)) than all previous vehicles including the Saturn V. In a typical Ares V ascent profile, the two Solid Rocket Boosters (SRBs) separate 125.9 sec after liftoff, are jettisoned and then recovered in the ocean. At 329.0 sec after liftoff, the core main engine shuts off and separates, and the Earth Departure Stage (EDS) ignites. At 802.3 sec the EDS engine cutoff occurs at about 240.8 km (130 nautical miles (nmi)). The Crew Exploration Vehicle (CEV), which is launched separately on an Ares I, performs a rendezvous and docking with the EDS. This docking procedure or loiter period is assumed to be up to four days. During this time, the orbital altitude is assumed to degrade to 185 km (100 nmi). Finally, the EDS Trans Lunar Injection (TLI) burn sends the Lunar Lander/CEV onto the Moon. The loiter skirt (shown in Fig. 1), which is connected to the EDS, supports this four-day loiter period. Presumably, on an Ares V mission used to launch an observatory, this loiter skirt and loiter period would not be required, which would add further to the payload capacity.

Sumrall discussed in detail the design concepts for all of the key elements of the Ares V including the EDS, the core stage, the notional instrument unit, the EDS J-2X engine, the SRBs, and the core stage upgraded RS-68 engine. Since all of this information is available on-line (http://www.nasa.gov/mission_pages/constellation/main/index.html) and not critical to how an Ares V could be used to launch large telescopes, we omit the details here. However, one element of the Ares V that is important for astronomical missions is the shape and interior dimension of the upper stage fairing. Sumrall presented a shroud shape trade study that they had done

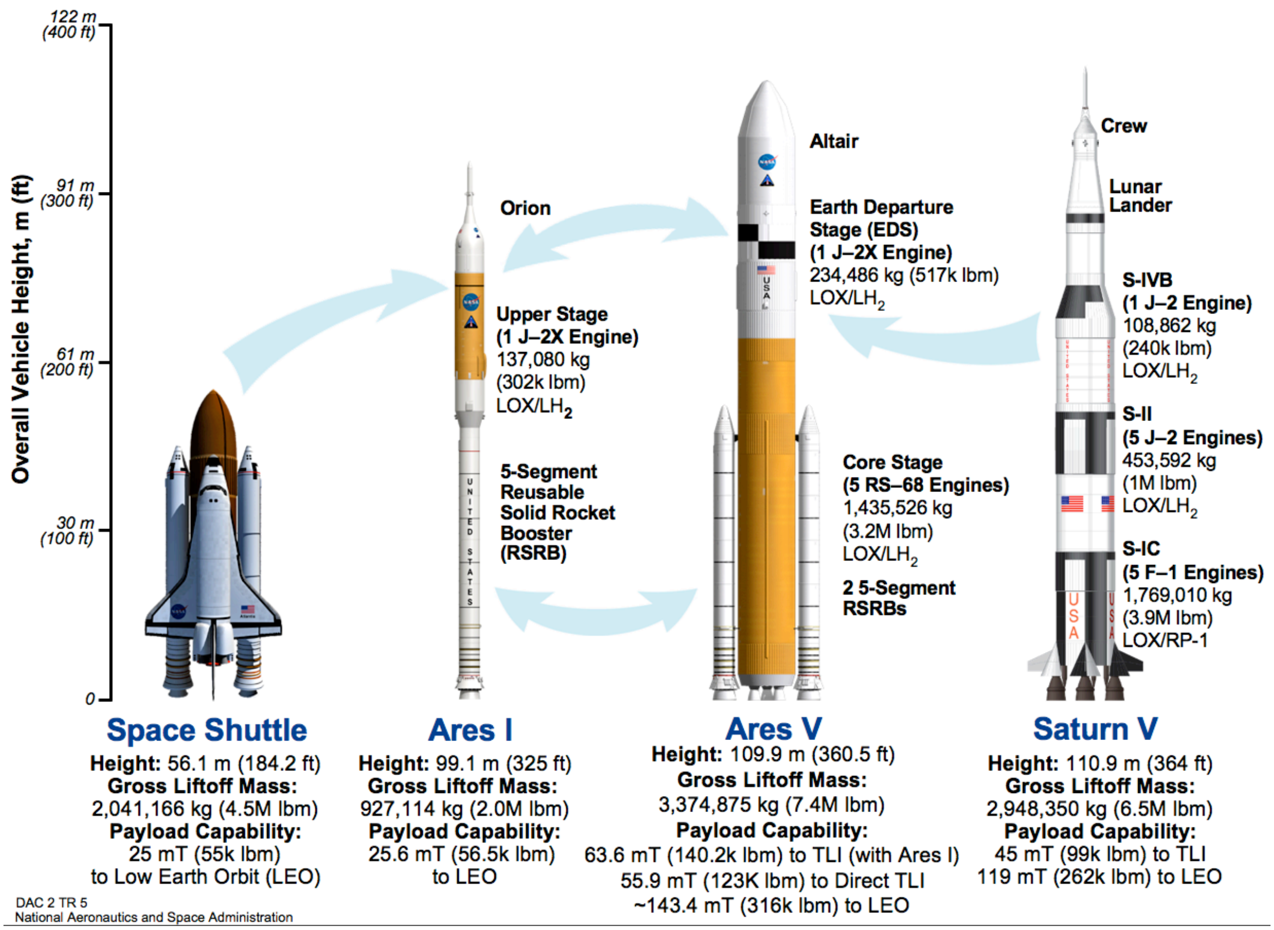

Figure 2. Building on a foundation of proven technologies—launch vehicle comparisons.

within the restriction of a 9.7-m barrel height. This barrel height is required to accommodate the current Altair Lander configuration. They considered many shapes such as hemispheres, tangent ogives, blunt cones, etc., but selected the biconic shroud shown in figure 3 as their baseline. A critical dimension is the 8.8-m diameter interior of the barrel. Shown in figure 4 is a notional Ares V shroud for other missions. The maximum length of the barrel is constrained to 18.7 m by the height of the Vehicle Assembly Building (VAB) at Kennedy Space Center. The increased barrel length reduces the payload mass capability slightly. For example, the payload to Sun-Earth L2 is reduced from 55.8 to 55.1 mT by using the extended fairing. For astronomical missions, the longer notional shroud was generally favored (see later discussion), because these missions are usually constrained by volume, not payload mass.

Sumrall also discussed the impressive Ares V escape velocity performance, which will be very important in reducing the travel time for planetary missions (a topic of a follow-on workshop). However, this will not be critical for launching large observatories, since they will reside in halo orbits around the Sun-Earth Lagrange points (L1 and L2). Preliminary analyses indicate that the payload environment (e.g., acoustic loads, vibration, cleanliness, etc.) should be comparable to other heavy launch vehicles and thus unlikely to negatively impact launching large telescopes. This is discussed in more detail for specific missions in the following sections.

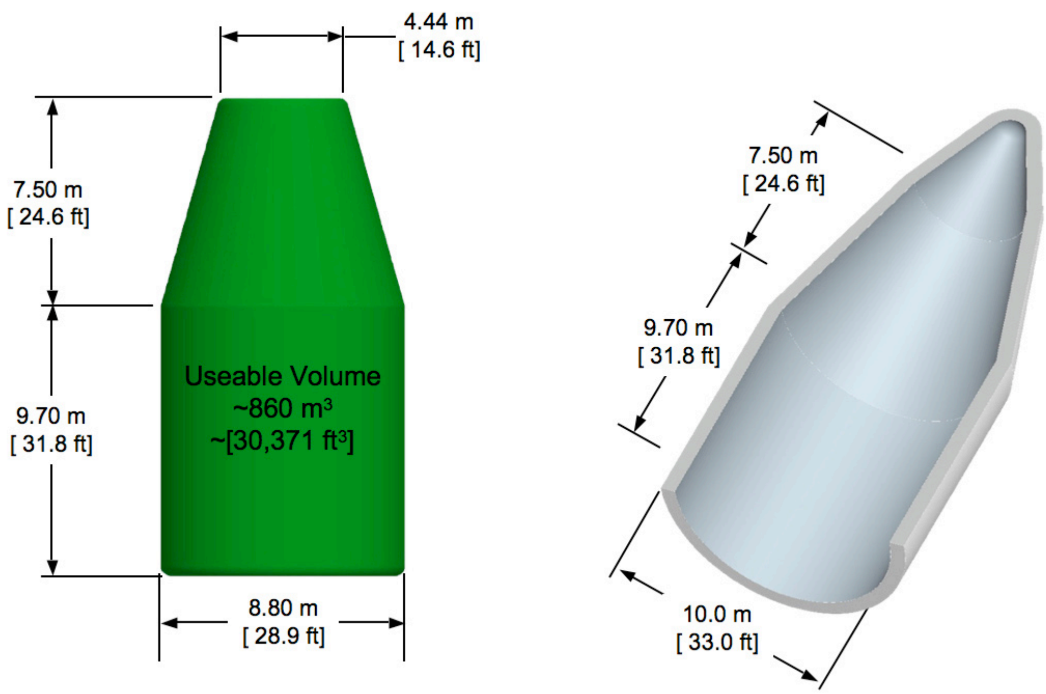

Figure 3. Current Ares V Shroud Concept.

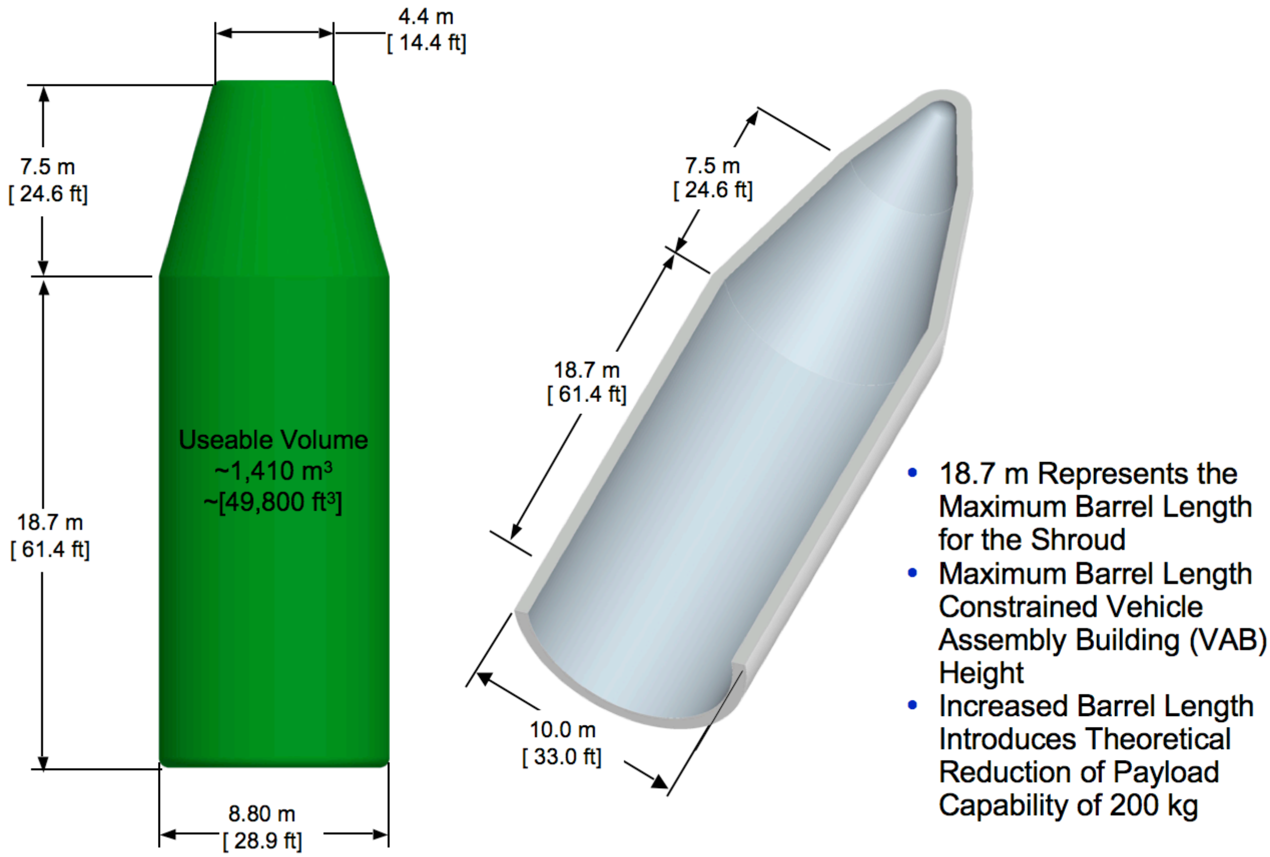

Figure 4. Notional Ares V Shroud for Other Missions.

Lessons from HST: Maximizing the value of large investments

Frank Cepollina presented a paper discussing the lessons that have been learned from the Hubble Space Telescope servicing missions. He began with a quote from NASA Administrator, Michael Griffin, who observed, "It is dumb to launch complicated, expensive telescopes into space that cannot be serviced." With the opportunity that Ares V presents to launch very large and potentially expensive telescopes, it is especially useful to consider on-orbit servicing as a means of expanding their scientific productivity.

The thesis of Cepollina's talk was that HST servicing missions have dramatically increased the scientific value of the telescope. Periodic changes in instruments to focus on new scientific questions, and the implementation of new instrument detector technology, result in a continuing rejuvenation of the scientific performance of this popular mission, and an enhanced pace of innovation and discovery. Cepollina described the history of on-orbit servicing missions beginning with the Solar Maximum Repair Mission. To date, there have been nine servicing missions to a variety of LEO satellites, which have shown that a satellite's design (e.g., standardized modularity) is the single most significant aspect of cost apart from launch costs. The sequence of HST servicing missions is shown in figure 5. To date, there have been four servicing missions, each time resulting in new scientific discoveries and an explosion of scientific papers. The SM4 servicing mission planned for Autumn 2008 will add the Cosmic Origins Spectrograph and Wide Field Camera 3, again extending the science capabilities of the telescope. To date, there have been over 6000 refereed papers generated from HST data. With the completion of SM4, Hubble will again be at the apex of discovery potential. The importance of on-orbit servicing in extending the lifetime and science capabilities of a telescope could not have been made more dramatically.

Looking toward the future, Cepollina discussed a concept for a piloted Orion servicing vehicle. He discussed the possibility of a servicing arm attached to Orion and controlled telerobotically by on-site astronauts. His scenario was to replace an instrument of a large telescope at its operational location at Sun-Earth L2 point or, alternatively, at the more accessible Earth-Moon L1 jobsite using an augmented Orion and Lunar Surface Access Module (LSAM). Cepollina reported on a study that compared costs of a series of expendable new telescopes versus a regularly serviceable telescope, which indicated that the servicing scenario was less costly. He ended by emphasizing that the time is now to start studying how elements of the Constellation program such as Orion could contribute to the science goals of the agency by extending human and robotic servicing missions to the next generation telescopes; that is, if we can do servicing missions with the Shuttle, why not with Orion?

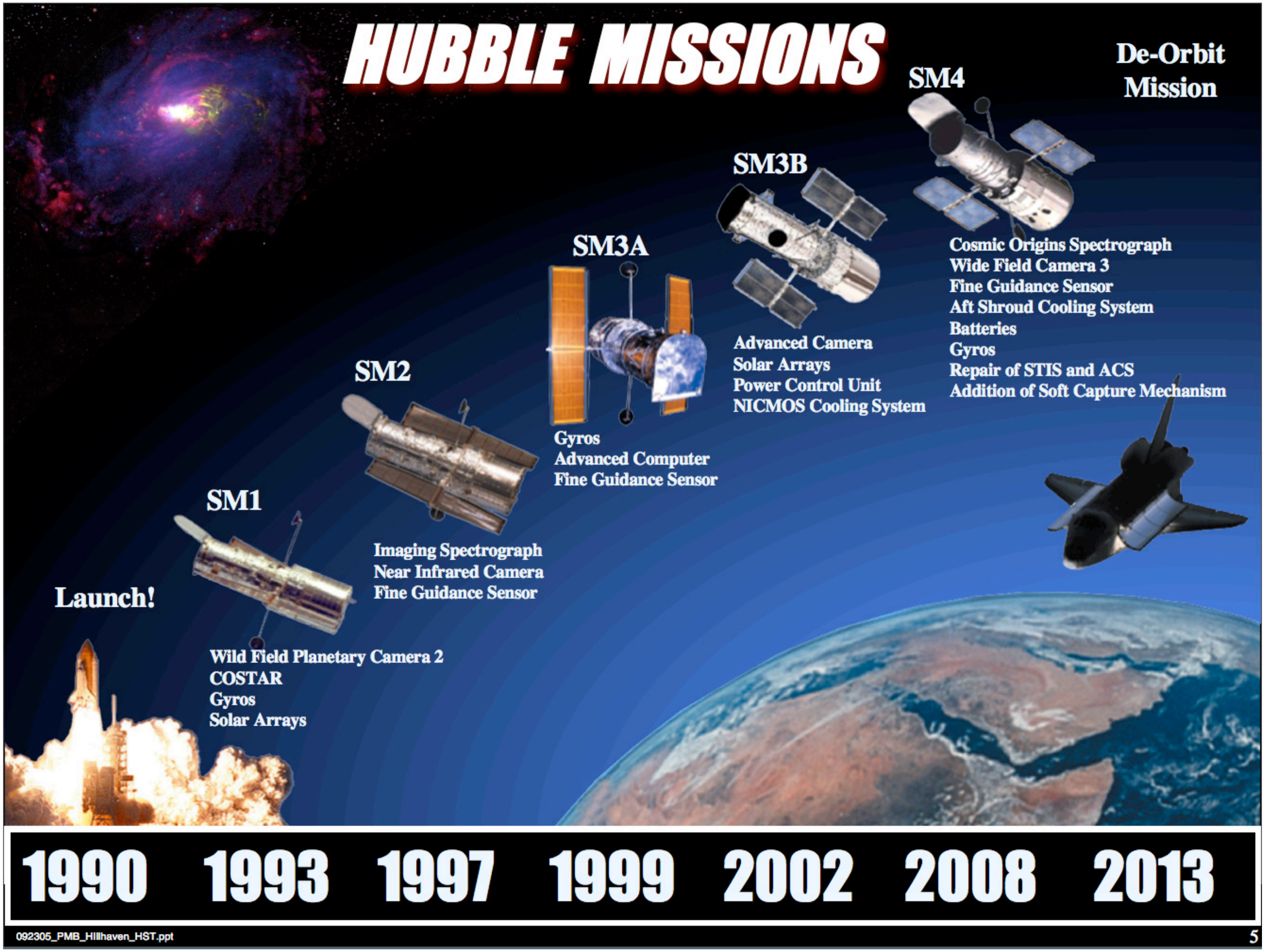

Figure 5. Hubble missions.

III. Telescope Concepts/Missions

Modern astrophysics aims to probe the full extent of the cosmos, from our own Solar System to nearby exosolar planets out to the most distant stars and black holes. Not only are the signals from many of these objects exceptionally faint, a full understanding often requires access to the entire electromagnetic spectrum, only a fraction of which is transmitted through the Earth's atmosphere. Even for those signals that do penetrate the Earth's atmosphere (both neutral and ionized components), astronomers require the vacuum of space to avoid the corrupting effects of the (neutral or ionized) atmosphere. The Ares V would be a significant enhancement for astronomical observations by allowing for much larger telescopes, which in turn enables much fainter objects to be detected and studied. In this section we summarize the presentations on seven astronomical concepts that are either enabled by or significantly enhanced by the availability of an Ares V launch vehicle. The order of presentation in the text is based on the order the papers were received by the organizing committee.

Emerging Pathways for the Single Aperture Far Infrared Telescope (SAFIR) with an Ares V

Dan Lester discussed how an Ares V could enhance the Single Aperture Far Infrared Telescope (SAFIR) concept. The large interior diameter of the Ares V shroud allows for a large single-substrate (monolith) primary mirror diameter of approximately 8 m. SAFIR is designed to obtain spectra in the far infrared (FIR) (~20-300 μm) using high performance focal plane FIR sensors. The entire telescope is cooled to less than 10 K by both passive and active means. SAFIR will explore the FIR universe with higher sensitivity and spatial resolution than previously achieved, providing new insights into the cosmic history of star formation and nucleosynthesis.

With an Ares V, the single-substrate 8-m mirror could be launched with no deployment mechanisms required. This could significantly reduce complexity, risk, deployment design, and integration and testing, which translates into reduced cost. Since SAFIR is diffraction limited at 20 μm, the optics are lighter than, for example, the James Webb Space Telescope (JWST). The launch mass is only 10 mT or ~20% of the launch capacity of Ares V for a mission to Sun-Earth L2. This would allow observatory augmentations such as more/larger instruments, as well as an enhanced spacecraft. Simple scaling of the SAFIR baseline concept, but with a JWST-like deployable primary mirror, would allow an ~20-m diameter telescope with 10 times the sensitivity and 2–3 times the spatial resolution to be accommodated in an Ares V.

A key message of Lester's presentation was the importance of servicing the spacecraft. For this to be feasible, the spacecraft would have to be modular to facilitate the replacement of the focal plane science instruments, spacecraft systems, and the solar shield. Instrument upgrades are particularly important in the FIR, for which detector sensitivity and array sizes are undergoing rapid improvement. Richards's Law observes that infrared detector sensitivity increases by a factor of two every two years. Thus, huge science productivity in the FIR comes from upgradeability of instruments on astronomical telescopes. Lester described a servicing concept where the telescope is brought back from its optimal operational location at Sun-Earth (SE) L2 to Earth-Moon (EM) L1, which is much more convenient for human travel. Transit from SEL2 to EML1 requires only a few tens of meters/sec delta-V (see later discussion). He ended by showing that the larger mirrors and greater sensitivity obtainable with next generation FIR detectors should make it possible to observe the very faint H_2 rotational lines from the early universe ($z > 10$) that would be red-shifted into the FIR. It would also be able to probe galaxies similar to that of our present Milky Way galaxy back in time when star formation was at a maximum.

ATLAST: The Roadmap to an 8-m to 16-m UV/Optical Space Telescope

Marc Postman described a concept for both an 8-m and 16-m UV/Optical Space Telescope that could be deployed from an Ares V. The Advanced Technology Large-Aperture Space Telescope (ATLAST) would have unprecedented sensitivity and angular resolution in the optical region. It could investigate a wide range of important astronomical issues, such as how the present Universe formed, how galaxies form, and how planetary systems form from circumstellar disks. In conjunction with a separately launched external occulter or a high performance coronagraph to block the light from the central star, it would be able to characterize the atmospheres of exosolar planets. The 16-m ATLAST, in particular, would be able to obtain spectra of the atmospheres of Earth-like planets in the habitable zone of thousands of candidate stars. This observatory would also have the required contrast and light-gathering capability to observe the matter immediately around a supermassive black hole.

As in the previous talk by Dan Lester, Postman also discussed the tradeoff between mass and mission complexity. Reducing complexity reduces risk and cost, thus an Ares V could reduce the overall cost of the mission by allowing a less-complex observatory. The huge mass lift capacity of the Ares V would contribute to the simplicity of the telescope design by offering structural strength and performance in bulk mass, rather than in elaborate trusswork. The huge volume capacity would contribute to the simplicity of the design by obviating the need for complicated deployment systems. For example, the Ares V enables a fully deployed 8-m or folded segmented 15- to 20-m telescope in a single launch. However, this would require the "tall" option Ares V fairing. Without an Ares V, multiple launches, complex folded optics, and/or on-orbit assembly would be the only alternatives for deploying a telescope larger than 7 m in diameter. Postman ended his presentation by discussing the technology developments that need to be made prior to launch. These include lightweight mirror technologies such as nanolaminate actuated hybrid mirrors or corrugated glass mirrors, and starlight suppression techniques using either an internal coronagraph or an external occulter. Designing the mission to enable on-orbit servicing was also noted as a high priority.

Stellar Imager (SI): Viewing the UV/Optical Universe in High Definition

Ken Carpenter discussed Stellar Imager, which is a space-based UV/Optical Interferometer with over 200 times the resolution of the Hubble Space Telescope. With its combination of high angular resolution, dynamic imaging, and spectral energy resolution, it is capable of performing breakthrough science in the UV/Optical spectral region. Science goals include an improved understanding of solar and stellar magnetic activity and understanding accretion mechanisms in sources ranging from planet-forming systems to black holes. The sub-milli-arcsecond angular resolution enables the study of dynamical structure and physical processes in currently unresolved sources such as active galactic nuclei (AGN), supernovae, planetary nebulae, and interacting binary stars. SI is also capable of imaging transits of exosolar planets across their stellar disks. Stellar Imager addresses science goals of both the NASA Heliophysics and Astrophysics Divisions. It is a candidate large-class strategic mission for the mid-2020s.

The Stellar Imager concept calls for a space-based UV/Optical Fizeau interferometer with a variable maximum baseline of 100 up to 1000 m. The interferometer is proposed to be located near Sun-Earth L2 to enable precision formation flying. The baseline concept consists of 30 1-m mirror elements focusing light into a single beam-combining hub. The baseline concept can be launched on a Delta-IV Heavy. The Ares V, with its much larger fairing volume, enables larger mirror elements, which dramatically improves sensitivity and reduces observation times. This increases the science productivity, especially for fainter extra-galactic sources and for astroseismic observations. In addition to larger mirrors, a single launch of an Ares V could also include more than one hub and a reference metrology/pointing control spacecraft. This would greatly increase the operational efficiency and robustness of the mission. The value of in-situ servicing, such as refueling and repairing or replacing damaged hardware, was also emphasized for this mission.

Generation-X: A Mission Enabled by Ares V

Roger Brissenden discussed an X-ray telescope concept known as Generation-X. The science goals include studying the early universe where the first black holes, stars, and galaxies formed, as well as their evolution with cosmic time. These first objects are expected to be powerful sources of X-rays, and X-rays penetrate both the haze of the early universe intergalactic medium, and the dust and gas around the objects themselves. The telescope would also provide new insights into the physics of matter in extreme environments. Key parameters in the baseline concept are that the effective area at 1 keV be 50 m^2 and the angular resolution be 0.1”. To meet the effective area requirement of 50 m^2 requires about 104 m^2 of glass area. This, in turn, requires thin mirrors (~0.1–0.2 mm) to meet mirror spacing and launch mass requirements, although the mass is less of an issue with the Ares V launch payload capacity. Since the requirements on effective area imply a 12 m diameter mirror, this would require either multiple launches and assembly, multiple satellites, or a single monolithic mirror that could only be launched on an Ares V.

The original mission concept using a Delta-IV Heavy called for six identical 8-m diameter telescopes, each carried as six segments to fit in the fairing. The Ares V enables a simplified and more cost-effective mission concept. The baseline concept calls for a partially filled 16-m diameter mirror, which folds to fit within a 10-m fairing. The X-ray telescope is delivered directly to Sun-Earth L2, and the estimated spacecraft mass of 22 mT is far less than the 55 mT capability to L2. Since the telescope is volume limited, not mass limited, the mass margin enables design freedom for the optics, structure, supporting electronics, and the science instruments. The ideal situation would be to have a fully filled ~12-m monolithic mirror that would need no deployment, thereby reducing cost and risk. The acoustic and launch loads require some consideration because of the thin mirrors, but probably would not be a problem if the Ares V launch environment were comparable to other heavy-lift vehicles such as Delta 4H.

He ended his presentation by discussing some of the technology developments that would be needed to enable the Generation-X mission. Significant improvements to the mirror figure control are required to achieve the high-angular resolution mission parameter. Innovative concepts using adjustable mirrors driven by piezoelectric actuators are under development.

Submillimeter Probe of the Evolution of Cosmic Structure (SPECS) Spectrometer Enabled by Ares V

Stephen Rinehart discussed the SPECS far-infrared (FIR) interferometry mission. This system consists of 4-m collector telescopes and a Michelson beam combiner with a one-kilometer baseline constrained by tethers. The interferometer is designed to achieve an angular resolution of 50 milli-arcseconds over a wavelength range of 40–640 µm, simultaneously obtaining spectral and spatial information using a double-Fourier technique. This would allow spatial resolution in the FIR that matches Hubble at optical wavelengths. Science drivers include studies of the first stars (whose light is redshifted into the FIR), galaxy evolution, star formation, and planetary and debris disks. The spectrometer is designed with sufficient sensitivity to map high-redshift extra-galactic sources.

The SPECS mission could be launched on a Delta-IV Heavy, but the larger fairing of the Ares V could be significantly enhancing. This would allow different packaging options, which would in turn lead to a much simpler deployment scheme. This represents a significant risk reduction, and could lead to significant cost savings by reducing the number of required mechanisms. In addition, the Delta-IV Heavy launch limits SPECS to a pair of 4-m monolithic mirror telescopes. While this would achieve the SPECS stated science goals, an Ares V would allow for both more and/or larger collector telescopes. Both larger telescopes and more telescopes would provide greater sensitivity, allowing both more and deeper (fainter) observations. Other potential benefits would be to use the larger launch payload of an Ares V to carry more propellant for a longer mission lifetime and to perhaps add a servicing spacecraft that could do both refueling and repair and replacement. DARPA's Orbital Express mission demonstrated such a capability in 2007.

The Dark Ages Lunar Interferometer

Joseph Lazio gave a presentation on the Dark Ages Lunar Interferometer (DALI) concept, a telescope designed to conduct cosmological observations of the so-called "Dark Ages" of the early universe and, potentially, of the Epoch of Reionization. The Ares V is likely to be required for the DALI concept, both because the extreme faintness of the desired signal requires substantial collecting area (and, hence, mass), and because the desired site for the telescope is the far side of the Moon.

The ground state of the hydrogen atom has the famous 21-cm hyperfine transition. After recombination, about a half-million years after the Big Bang, the dominant component of the intergalactic medium (IGM) is atomic hydrogen, and the predicted temperature of the gas eventually drops below that of the cosmic microwave background (CMB). Even well into the Epoch of Reionization, the IGM remains dominated by neutral hydrogen, although a more complicated temperature evolution is predicted as the first stars and black holes form and heat and ionize the IGM. Depending upon the redshift, the hyperfine transition should be seen in either absorption or emission against the CMB, and would serve as a cosmological probe in much the same way that the CMB itself has been over the past four decades. Importantly, the redshifted 21-cm transition may offer the opportunity to follow the evolution of the Universe during this crucial epoch. Secondary science includes studying the magnetospheric emission from exosolar planets and heliophysics.

The baseline DALI concept calls for a large number (hundreds) of antenna "stations," with each station consisting of 100 antennas. The nominal location is the Tsiolkovsky crater on the far side of the Moon. The stations would be deployed with robotic rovers, and signals from the stations would be transmitted via laser links to a correlator. The Moon's far side may be the only place in the inner solar system where these observations can be carried out, due to strong terrestrial (human-generated) emissions in the radio that are effectively blocked in this far-side location. The current antenna concept consists of dipoles deposited on polyimide film. Each rover would unroll the polyimide film rolls for its station, then remain in place to serve as a "transmission hub," beaming the signals from its station to a central processing facility. Aspects of the Constellation System, both the Ares V and the cargo version of the Altair lander, present an attractive means of deploying the large launch mass of the telescope, which is dominated by the antennas and rovers, on the farside of the Moon.

Starshades in the Ares V

Tupper Hyde reviewed the next generation missions to characterize exosolar planets using a starshade in the context of what an Ares V might enable. He discussed the sequence of missions to characterize exosolar planets beginning with the baseline New Worlds Observer Spectroscopy mission to characterize planets at low spectral resolution. This mission could be carried out with current heavy-launch vehicles. The next most advanced mission is Lifefinder that would carry out medium resolution spectroscopy (R ~ 10000) of the atmospheres of exosolar planets. This would require a large 8- to 16-m telescope in conjunction with a starshade. Here an Ares V would be enhancing, but not absolutely essential. The next most ambitious mission called Planet Imager, which requires multiple telescopes to carry out large-baseline imaging interferometry plus starshades, could only be carried out with an Ares V.

In all of these mission concepts, the starshade is used as an external occulter to block the light from the star. The telescope needs to be large enough to collect enough light from the planet and needs to be far enough away from the starshade to have a suitably small inner working angle. Low-resolution spectroscopy (R > 100) would be sufficient to distinguish terrestrial from Jovian atmospheres, for example. At this resolution it should be possible to detect oceans and continents using photometry. Hyde showed that resolution, and thus mirror size, is critical. He then described the New Worlds Imager concept in the context of the Ares V, where much larger mirrors would be enabled. Since Ares V enables large volume and mass to Sun-Earth L2 or Earth drift-away orbits, Ares V launches loaded with multiple telescopes and starshades would enable the following: (1) A single 8-m telescope and two starshades; (2) two 4-m telescopes and four starshades; or (3) an imaging interferometer: Combiner fed by two or three collector telescopes with starshades. Like many of the astronomy missions, a fairing taller than baseline is preferred.

Panel Discussion on Strategic Trades and Questions

The workshop began on the second day with a panel discussion entitled “strategic trades and questions.” The seven astronomers who presented telescope concepts on the first day were panelists. This was an opportunity for the scientists to discuss with the Ares designers what were the drivers in the payload environment for their mission concept. The chart in figure 6 summarizes the drivers for the seven telescope concepts presented at the meeting. It should be noted that many of these missions have Evolved Expendable Launch Vehicle (EELV) baseline options. The answers in the chart refer to enhanced concepts that take advantage of the Ares V capabilities. For example, the SAFIR column refers to a large single-substrate primary mirror baseline of approximately 8 m. This larger mirror could be launched without deployment mechanisms on an Ares V, thereby reducing complexity, risk, and probably cost.

As can be seen from the chart, most of the payloads are limited by volume, not mass. As discussed previously, a longer shroud is very advantageous for some of these concepts (ATLAST, SI, and Starshade), while the Gen-X and SPECS payloads would benefit from a larger diameter shroud. In most cases, the expected launch environment for the Ares V (acoustics, cleanliness, and power) is adequate for these astronomy missions. However, neither the mission concepts nor the payload environment have yet been defined adequately to be definitive.

One of the discussion topics in the panel discussion was the availability of the Ares V. Many felt that for Ares V to be viewed as a viable resource for robotic space science missions, it needs to devote at least one launch vehicle to such a mission (including Earth science, planetary science, heliophysics, astrophysics, or other government agency payloads) every several years or so. However, the issue of availability of Ares V to the science communities, its cost, and the impact on its primary mission of returning humans to the Moon were considered critical topics for future discussion.

	SAFIR	ATLAST	SI	Gen X	SPECS	Dark Ages	Starshade
Volume (Driver Y/N)	Yes	Yes	Yes	Yes	Yes	No	Yes
Mass (Driver Y/N)	No	No	No	No	No	Yes	No
Shroud Length	No	Yes	Yes	No	No	No	Yes
Shroud Diameter	No	No[1]	No	Yes[2]	Yes	No	No
Acoustic (Driver Y/N) **No = Current Shuttle Environment**	No	No	No	No	No	No	No
Cleanliness (Driver Y/N) **No = Current Shuttle Environment**	No	No	No	Yes[3]	No	No	No
Power/Data (Driver Y/N) **No = Current Shuttle Environment**	No	No	No	No	No	No	No
Other Sensitivities	No	No	No	UNK	No	No	No
Enabling (ENB): Enhancing (ENH)[4]	ENH	ENB	ENH	ENB	ENH	ENB	ENH

UNK = Unknown at this time

Notes:
[1] Assumes 16-m segmented telescope will be folded for its launch configuration
[2] Non-folded 12-m telescope
[3] X-ray and near-UV optics may need better cleanliness
[4] "Enabling" means enabling in a single launch vehicle, perhaps with much lower deployment risk. "Enhancing" means that the baseline missions can be done in a smaller launch vehicle, but Ares V offers straightforward opportunities for more ambitious versions of the mission.

Figure 6. Ares V astronomy payload summary.

IV Technology Challenges

Future Space Robotics and Large Optical Systems

A strong theme in the workshop was the attractiveness of servicing the large astronomical observatories that an Ares V is capable of launching. Our servicing experience to date is primarily with the Hubble servicing missions that have been performed by astronauts. However, in part because we would like to service observatories further from Earth, e.g., out at SEL2 or EML1, robotic servicing missions become an attractive alternative to human servicing. The feasibility of autonomous on-orbit servicing was clearly demonstrated in the next paper by Tracy Espero.

Tracey Espero discussed the very successful DARPA Orbital Express mission and the future of space robotics and large optical systems. Orbital Express (OE) demonstrated the technical feasibility, operational utility, and cost effectiveness of autonomous techniques for on-orbit satellite servicing. Specific objectives of OE were to demonstrate on-orbit propellant and component transfer and autonomous rendezvous, proximity operations and capture. The overarching OE objective was to demonstrate the technical feasibility of autonomous on-orbit satellite servicing.

Orbital Express was launched on March 8, 2007 into a 492-km circular 46-degree inclination orbit. It consisted of two separate spacecraft, the Autonomous Space Transfer and Robotic Orbiter (ASTRO) servicing spacecraft and the Next Generation Satellite/Commodity Spacecraft (NEXTSat) serviced (or client) spacecraft (see fig. 7). ASTRO used a hydrazine monopropellant reaction control system

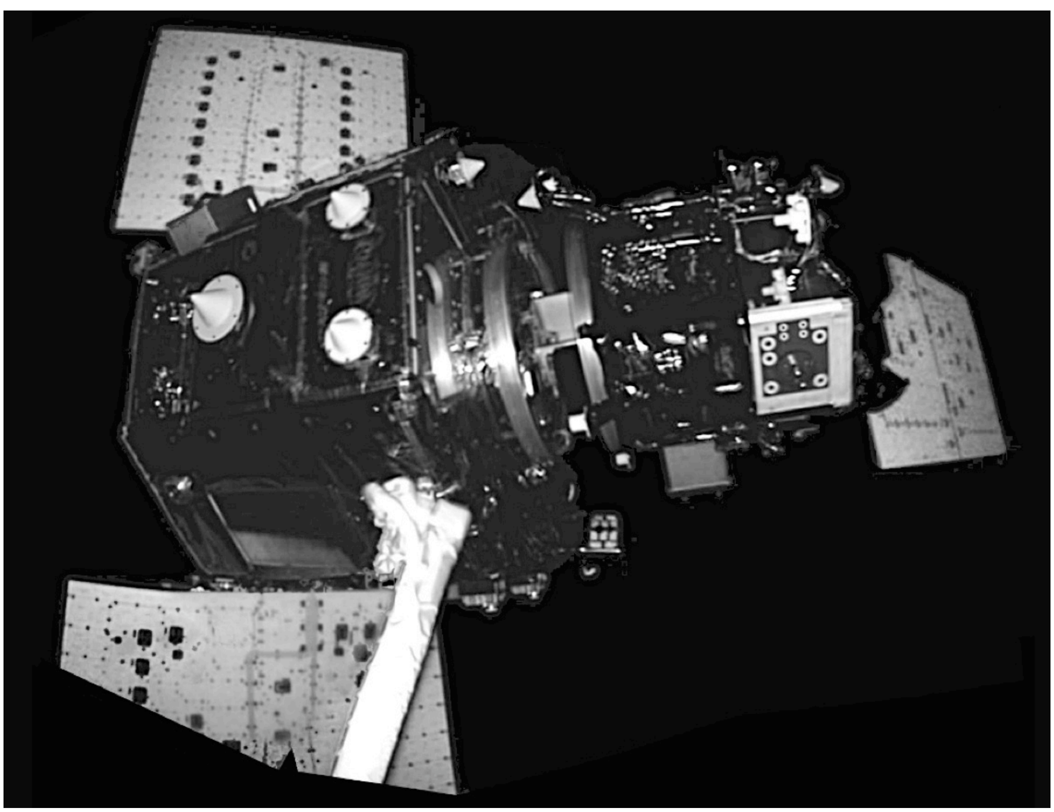

Figure 7. Orbital express self portrait.

for six degree-of-freedom control. It had a number of active servicing functions such as rendezvous and proximity operations sensors, a robotic arm, and an active capture system. NEXTSat had attitude determination and control, but no maneuver capability. It had standard servicing interfaces for all orbital replacement units (ORUs). The importance of modularity and standard interfaces were stressed. The ASTRO servicing spacecraft successfully demonstrated propellant transfer to NEXTSat with varying degrees of autonomy. It also performed battery and computer transfers flawlessly. ASTRO used an autonomous Guidance, Navigation, and Control (GNC) software system for demate, separation, departure, rendezvous, proximity operations, and capture. The advanced robotic arm on ASTRO was used to drive a camera at its tip to aid in capturing NEXTSat. The importance of having cameras on the servicing spacecraft was stressed. The OE mission accomplished many firsts, such as the fully autonomous propellant and ORU transfers, free-flyer capture, and long range (> 400 km) rendezvous. This suggests that it would be possible to service large astronomical observatories in space. Although not included in the original goals of the meeting, the importance and feasibility of fully autonomous robotic on-orbit servicing of spacecraft was a recurring theme in the workshop.

Future Deployment Systems and Very Large Fairings

Chuck Lillie presented Northrop Grumman's concept for the future of deployment systems and very large fairings. He began by discussing the James Webb Space Telescope (JWST), since it represents the current state of the art in large space observatories. He noted that technology improvements have changed the cost to aperture scaling "relationship" that is often quoted, namely that cost is now proportional to aperture to the 2.5 power. He predicted that further technology development plus infrastructure changes (such as the Ares V) will improve our ability to produce cost effective large observatories. This optimistic view is dependent on a continued technology investment program into advanced optics technologies such as replication, improved wavefront sensing, and control technologies, as well as advanced deployment and assembly technologies.

He discussed the possibility of a 16.8-m version of JWST that could be stowed in the Ares V notional fairing (i.e., a fairing that is longer than the current baseline) with a "chord-fold" deployment system. A preliminary analysis indicates that this augmented 16.8-m version of JWST would fall within the Ares V lift capacity. He also discussed a 21-m diameter stacked hex deployment that deploys seven 8-m pt-pt hexagonal mirror segments, and a 24-m diameter fan-fold deployment telescope that contained 12 pie-shaped segments. All of these concepts require the taller Ares V notional fairing. Although these deployment concepts may add complexity, he demonstrated that complex deployments could be done with a high probability of success. The 24-m fan fold concept has 426 m^2 area compared with 27 m^2 for the 6.6-m baseline JWST.

He noted that the standard Ares V fairing severely constrains payload packaging aperture size. For example, it would constrain the chord fold packing to 12-m versus 16.8-m diameter for the notional fairing. The notional fairing's mass, volume, cylinder height is well suited for optical payloads and is consistent with payload accommodations on current launch vehicles.

Lillie concluded by noting that the Ares V will enable a new generation of very large space observatories, and furthermore, that these large space observatories can be built in the next decade if they take advantage of newly developed technology and investments in current observatories. To achieve this goal, however, we must have a sustained development program in deployment technologies, among other areas, even as NASA has reduced its investments in future technologies of all kinds. Finally, he noted that capabilities are developing that could radically alter how we approach space observatories (such as Ares V) and improved abilities to service and upgrade future observatories in space.

Libration-Point and Lunar-Swingby Trajectories

Since we are interested in putting large observatories at libration points such as SEL2, it is of interest to discuss whether humans can get there to do servicing. Bobby Williams presented a paper on libration (or Lagrange) point and lunar swingby trajectories. These trajectories enable space telescope servicing either by transporting a repair team to, for example, Sun-Earth L2 (SEL2) or by returning the telescope to an elliptic Earth orbit. In presenting this paper they made the assumptions that large space telescopes at SEL2 will require servicing, repair, or other upgrade, that human space exploration will continue, and that the Constellation vehicles Orion and Ares I will be developed. To help orient the reader, figure 8 shows all of the libration points in the vicinity of the Earth. To illustrate that these libration points of interest are not stable, figure 9 shows an example of a trajectory from Earth to SEL1. The spacecraft is placed into a halo orbit around SEL1 with an orbital period of approximately 6 months. Examples of fast transfer trajectories from Low-Earth Orbit (LEO) to the SEL2 point were also shown. The minimum delta-V to SEL2 is about 338 m/sec with a transit time of approximately 36 days.

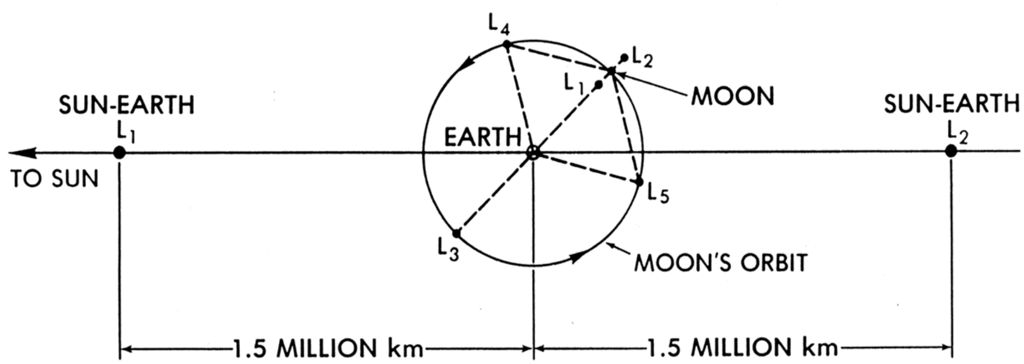

Figure 8. Libration points in the vicinity of the Earth.

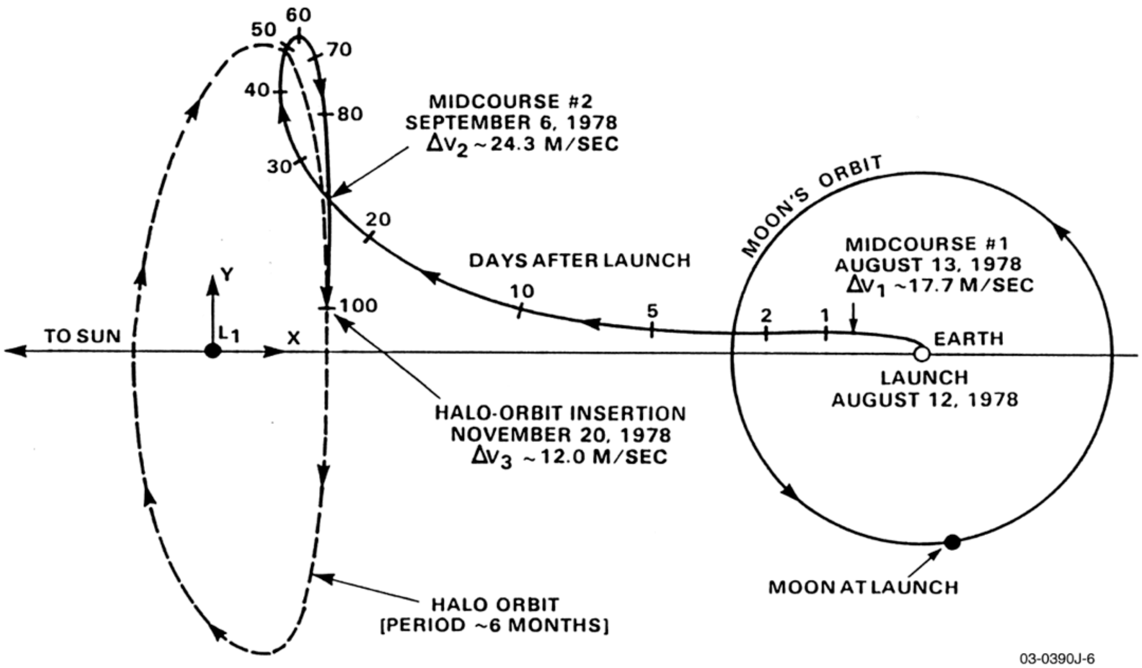

Figure 9. ISEE-3 slow transfer trajectory to halo orbit.

Williams presented an Interplanetary Transfer Vehicle (ITV) mission scenario for telescope servicing at the SEL2 libration point. The Deep-Space Shuttle (DSS) leaves low-Earth orbit with a delta-V of 3230 m/sec and enters an L2 orbit with a delta-V of about 900 m/sec. The DSS services the telescope that is in a halo orbit around SEL2 for a period of five days, and then exits L2 with 900 m/sec delta-V. The crew then returns to Earth in an Apollo-style capsule. The trip time is about 35 days. He presented a number of other mission scenarios to Near Earth Asteroids (NEAs).

An important point is that the delta-V requirements for lunar, geosynchronous, and SEL2 are similar. He recommended using a low-cost, low-risk incremental approach to developing capabilities. First, develop the DSS, which has transit times of 2 days to geosynchronous orbit, 10 days to lunar orbit, and 30 days to SEL2. This would provide the capability to service space telescopes that are in halo orbits around SEL2.

In key respects, a more attractive scenario would have the telescopes travel from SEL2 to an Earth-Moon L1 "job site" and service them there with robots and/or astronauts. This jobsite is 84% of the way to the Moon and, while it is not an optimal site for telescope operation, is easily accessible to lunar-capable constellation architecture, offering relatively quick return to the Earth or refuge to the lunar surface in case of problems. This option requires very little delta-V to move the telescope, and is highly advantageous in terms of mission length for astronauts. In this scenario, the telescope, rather than the astronauts, has to travel for a month or more. Finally, Williams recommended developing the ITV for missions to NEAs and beyond.

Optical Testing of Ares V Large Optical Spacecraft: The LOTIS Collimator Option

Steve West presented a paper on the optical verification of large optical spacecraft using the Large Optical Test and Integration Site (LOTIS) collimator. LOTIS is an advanced integration facility designed to test mirrors with apertures as large as six meters from 0.4–5 μm in wavelength. The LOTIS facility, located in Sunnyvale, CA, is a large-scale facility containing clean rooms, high and low-bay integration areas, test control facilities, etc. The goals of the facility are to produce a greater than 6-m collimated beam in air or vacuum, and provide active wave front control yielding small sub-aperture wave front errors. The LOTIS collimator is a joint effort between Lockheed Martin and the University of Arizona Steward Observatory. The main components of the 6.5-m LOTIS collimator are the primary mirror cell and actuators, the primary mirror with 36 Hartmann mirrors, eight Ivar truss tubes, a secondary mirror mounted on a five degree-of-freedom hexapod, and the collimator head ring and support structure. The primary mirror is scheduled for delivery to Sunnyvale in June of 2008. Phase III integration and testing in air is scheduled to be completed in November of 2008, and vacuum testing and validation is scheduled in early to mid-2009. Once construction is finished, a unique test facility will be available for testing large aperture mirrors.

V. Breakout Sessions

In the afternoon, the workshop participants broke into three groups to discuss some specific questions in more detail. The first group chaired by John Karcz looked at what breakthrough science could be enabled by an Ares V. The second group chaired by Gary Martin addressed both technological and environmental payload development issues. The third group, co-chaired by Randy Correll and Phil Stahl, addressed the question of whether there was value in simplicity. In other words, could payloads be made less complex and thus less costly if mass was not a constraint.

Breakout #1: What breakthrough astronomy might be enabled by Ares V?

Telescopes flown on Ares V will undoubtedly have scientific capabilities significantly in excess of those of current space observatories. Those capabilities may lead to breakthrough results that are unattainable from current facilities. Over the next ten to twenty years, though, it may be possible to obtain some of those capabilities through other means, such as assembly of large aperture observatories in space or by flying formations of spacecraft from multiple smaller launchers. The breakout group considered potential breakthrough astronomical investigations foreseen for observatories flown on Ares V and tried to discern which would be uniquely enabled by this new launch vehicle.

The group concluded that there was no astronomy that was uniquely enabled by an Ares V, but observations that might be feasible through other means (for example, with multiple launches on smaller vehicles, and in-space assembly), become more practical with an Ares V. For example, payloads may be cheaper per unit volume and mass, or less complex with less deployment risk. Also, an Ares V may enable astronaut servicing missions of telescopes at remote locations, if this proves to be an optimal strategy.

Examples from NASA's strategic astronomical goals, where large apertures are needed, are studies of the early universe, formation and evolution of large-scale structure in the universe, the chemical evolution of the universe, and exosolar planetary science. Astronomers would like new observatories to have an order of magnitude improvement in some metric such as sensitivity, angular resolution, field of view, etc., to open sufficient discovery space to enable breakthrough science. Ares V will make achieving this kind of improvement more practical. The group also felt that the astronomical community needed more time and resources to reevaluate their long-term goals in light of the new capabilities afforded by an Ares V heavy-lift vehicle.

Breakout #2: Payload development: Technology and environmental issues

While the Ares V presents a great opportunity for the astronomy community, there are technology and launch environment issues that should be considered to allow full use of the heavy lift and large volume available with the Ares V rocket. A long list of potential technologies was discussed, and the areas that were considered the highest priority were narrowed down so that the Ares V team can focus on enabling design features.

The Ares V baseline design is already very good for astronomy missions. Specifically, the vehicle's mass and fairing volume capabilities are enabling technologies for new science missions. The ability to support the payloads with power and data/health monitoring meets expected requirements. The areas the team felt were enabling and needed further study are described below.

Fairing Volume

The volume of the fairing was considered to be the highest priority design issue that could enable large breakthrough astronomy missions. Increased volume can be achieved by increasing either the diameter or height of the fairing or both. The Ares V designers felt that increasing the diameter past the current baseline of 10 m would be both costly and difficult, because the body of the entire rocket is 10 m in diameter, and designing a hammer-head payload fairing on such a large vehicle presents significant challenges. The designers noted that while the Ares V fairing is designed to support the Altair Lunar Lander, a modular fairing design could probably be extended in height up to what is allowed within the Vehicle Assembly Building (VAB). To go higher would involve costly modification for the VAB. The Ares V designers agreed to study modular designs that would support taller fairings.

Launch environment

The team felt the launch environment was crucial to sensitive astronomy facilities. However, the large payload capacity of the Ares V allows flexibility to make the telescope more rugged.

Static loads:

Since large astronomy observatories such as Hubble have been launched with the Shuttle, the group felt that the Ares V should not provide a launch environment that would be more stressful than a Shuttle payload could endure. The Ares V designers stated that the engines are designed to be throttleable, which can be used to help control the static loads on the payload during take-off.

Dynamic and acoustic loads:

The goal for Ares V should be as good or better than the current launch environment on other heavy-launch vehicles such as the Shuttle, Atlas, Ariane, and Delta rockets. The Ares V designers will use the metric of "as good as the shuttle" as a point of departure on trade studies.

Cleanliness

Astronomy missions have extremely sensitive instruments and cleanliness is an important issue. The fairing of the Ares V should support a continuous N_2 purge during integration and pre-launch activities at the pad. This will ensure that the instruments and surfaces will not be contaminated by the launch vehicle. The Ares V should also use the Shuttle cleanliness requirements as a point of departure on trade studies.

Mission Capability

The destination for many astronomy missions is the Sun-Earth L2 (SEL2) location, since it provides a better thermal environment, more stable power, and better observation opportunities. Unlike human missions to the Moon, in which Earth-orbit rendezvous is part of the mission plan, it is desirable to launch observatories to SEL2 on a direct mission profile without going into Earth orbit. This would have the added advantage of avoiding the need for the loiter collar, thereby resulting in savings in both cost and mass.

One major exception presented at the meeting was the DALI concept that uses one or more Ares V vehicles to deploy a very large number of dipole antennas on the dark (at radio wavelengths) lunar farside . In addition, the cargo version of the Altair system was identified in the baseline concept for this mission for carrying the observatory elements to the lunar surface.

Support Servicing, Maintenance, and Upgradeability

It also appeared desirable for the Constellation system to be capable of enabling both human and robotic servicing missions to telescopes, for example, at SEL2 or at an Earth-Moon libration point "jobsite." Servicing astronomy facilities in space greatly increases the science output, which has been demonstrated by the Hubble Space Telescope. This capability would enable maintenance, repair, and upgrading of future astronomy facilities well into the future.

Support for secondary payloads important (to take advantage of excess mass)

The group felt that since most astronomy payloads did not require the full mass payload afforded by an Ares V launch, secondary payloads or missions of opportunity should be considered to fill any excess volume. To take full advantage of this approach, the group recommended that the Ares V team design a standard payload adapter similar to the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring. This would only slightly increase the height of the vehicle.

Breakout #3: Is there value in simplicity?

Overview

A major concern in considering the use of super-heavy-lift launch vehicles is whether or not the very large payloads they would deploy are affordable in their own right. Current heavy-lift launch vehicles have deployed NASA complex space science missions costing in the $5B cost-range. If we were to increase the size and mass of such missions by a factor of five times, would the science budget be able to afford missions that cost up to $20B or more? It is conventional wisdom that a major predictor of mission cost is mass. However, mission complexity is also a major driver of mission cost, and may even be the dominant factor.

Cost models vary in their details, but one representative cost model, the NASA Advanced Mission Cost Model , presents figures very close to those mentioned above for missions based on their mass, but rated high in their technical difficulty. The same cost models show that historically, missions of the same mass, but of average difficulty, would cost only about $10B, or about half the price. This leads mission designers to consider what could be gained by using the increased mass and volume of the Ares V launch vehicle to reduce complexity, and hence cost, to allow the deployment of space science missions of increased capability, but of similar or only slightly reduced cost to those that are deployed with current launch vehicles.

Some questions to consider

Complexity allows principal investigators and mission designers to gain performance from a volume and mass constrained launch system. By reducing these constraints, the Ares V enables a new paradigm—reduced cost and risk by designing simple, less complex systems. Thus, the workshop recommended exploring how Ares V permits 1) enhanced mission performance; 2) reduced risk; 3) more optimized schedules; and 4) reduced cost. To do so, the scientists and engineers will need to consider how the additional mass and volume can lead to simple and rugged designs. This will also lead to a re-thinking of the ground processing and testing infrastructure for simple and rugged, but also larger and heavier spacecraft, apertures, and components. Along with this, designers will have to consider if modular approaches to systems design and the potential use of on-orbit assembly and servicing can be used to lower risk and cost. While modularity and servicing often entail additional features in the design, these are not always of increased complexity, and with creative thinking at the beginning of the design, the overall systems engineering may lead to a lower-cost solution.

Mass and Volume – Simplicity trades

Typically, the highest priority of telescope design is the size of the primary aperture of the system. Large apertures are needed for cutting edge science, and current approaches such as the James Webb Space Telescope rely on a fairly complex segmented optic system that must be carefully deployed and stowed, protected from the harsh launch environment, and then deployed in space for operations. This complexity leads to increased risk and cost although to date both have been considered manageable. To deploy even larger apertures in space, the Ares V would allow for a monolithic optic. Reduced need for stowing and deployment is estimated to produce a 30% savings in overall mission development cost, although with the loss of a light-collecting aperture. Thus, the space program could take advantage of the lower cost of primary mirrors that are produced for ground-based telescopes with relatively minor modification, and often even simplifications to their manufacturing process, given that the large optic deployed in space is less susceptible to concerns of gravity offloading and sag in the optic. A preliminary, nominal design for a 6-m integrated telescope and spacecraft (but not including instruments) was presented at the workshop with a cost of $1.2B and mass of 35 mT.

Additionally, the increased mass capacity of the Ares V allows for the addition of more support and isolation structures to protect the telescope from launch accelerations, vibration, and acoustic loads. Similarly, designers can consider how to build sturdier designs that could save in the expense of handling fragile spacecraft versus sturdy structures. The increased mass margins for designing components and structures should by itself simplify the design and fabrication, and thus reduce cost.

Aside from the space telescope optics, the increased mass may allow for simpler, less expensive instruments. For example, it would be easier to use mass as shielding instead of typical rad-hard electronics and instruments. COTS electronics could be used in containers with an ambient environment similar to earth-like conditions. Additional redundancy could also be deployed where the price of additional components is less than a more complex solution that is mass constrained. Perhaps the largest savings in these mass and volume unconstrained concepts is that they greatly reduce risk of overall program cost growth and technical risk. Another rule of thumb is that it nominally costs about $1M/kg to solve problems that arise during spacecraft and instrument development. With extra mass and volume margins, simpler solutions could be employed that saved money directly, and that also saved money indirectly in that the reduced time to solution reduces the cost of an idle workforce.

Finally, modularity needs to be considered in these designs. Modularity can already provide cost-saving benefits in that subsystems and modules can be independently tested before integration. Additionally, if problems come up during integrated testing, the modules are easily disassembled for repair or rework, where in tightly integrated designs, the disassembly and subsequent reassembly can be very complicated, risky, and expensive. For larger and heavier spacecraft designs considered for Ares V deployment, the need for handling fixtures and test facilities will almost require that a modular approach be used.

Servicing

The Hubble Space Telescope has provided a rich history of the costs and benefits associated with the servicing of a space observatory. Most significantly, it allows for reduced risk in deployment and operation of space observatories. This reduces the cost of the space observatory design, but brings along the attendant cost of having servicing capabilities. Given that servicing infrastructure exists, as in the case of the human spaceflight program, or in the new robotic servicing technologies such as those recently demonstrated by the Orbital Express program, servicing options might be available for consideration for Ares V-class missions.

Servicing also allows for upgrades of instruments over time, thus providing a lower system life-cycle cost. This raises the question of the overall science plan and architecture: does NASA prefer a series of completely independent space telescope missions every five years, or do they deploy a single space observatory and upgrade only the instruments every five years? Many people in the astronomy community make the case that this is more cost effective, and this is a point that will need to be considered by any space-based science plan for the future.

Critics point out that servicing as part of the assembly and deployment of a space telescope adds additional cost through extra workforce and equipment. While there is cost associated with this infrastructure, it is important to consider the overall life-cycle cost, especially if servicing infrastructure is already available and supported by other resources. Given the increased interest in science missions of many kinds at libration points, it is conceivable that there would be an overall savings if NASA and other space organizations invested in servicing and resupply infrastructure to support extended operations there.

One final point is that, given the value of space observatories such as HST and JWST, and even more ambitious missions considered for the future, could NASA afford to have such a high-value asset deployed in space without the capability to repair the system if it were to fail to properly deploy?

Cultural Issues

Finally, we want to address important cultural issues. We are only beginning to explore a new paradigm for space-based astronomy missions using the Ares V capability. Much of our thinking will need to change radically to make this a cost-effective endeavor and enable breathtaking new capability. When one considers the cost of any large, complex system, fundamentally, people are cost. Can we break the paradigm of assigning the number of people to the anticipated cost, or can we have the same number of people accomplish more, and on a much grander scale? If we can find ways to translate the greatly enlarged mass and volume margin afforded by the Ares V into simple, rugged, and less demanding components and systems designs, we should be able to achieve new levels of affordable space-astronomy capability.

Actions and recommended further activities from the workshop groups

As we are only beginning to consider the new possibilities here, clearly more rigor needs to be applied to all of our assumptions and conjectures about where cost can be saved. As a first action, and for a simple reference point, we recommend NASA Goddard and NASA Marshall compare the current segmented JWST space telescope with a monolithic design. Specifically, the following two options should be examined:

Option 1—segmented mirror- like JWST design for EELV launch

Option 2—monolithic mirror and other mass-unconstrained approaches for Ares V launch

This will provide a handy reference point based on the state of the art as we know today. Further studies could then be conducted to consider more ambitious missions.

A second action is to determine what the astronomy community would really require for the long-term future architecture of space-based astronomy, which is primarily the responsibility of the National Academy "decadal review" process. Will the largest monolithic telescope discussed at this workshop (i.e., 8 m) be sufficient? Or will deployable or assembled designs need to be pursued, even on an Ares V-class booster? If this is where the scientific frontiers lie, we must find ways to pursue them in an affordable manner.

As a third action the group recommended that the Ares V design team develop a Design Reference Mission (DRM) for a large astronomy payload and consider what would be required to enable on-orbit observatory servicing.

Research priorities: where do we go from here?

In his wrap-up discussion at the workshop, Pete Worden expressed the view that the science case for the Ares V is impressive. The astronomical community needs to consider developing an "elevator speech" that captures in a few words the breakthrough science that this new launch vehicle enables. He also expressed the view that we needed to have funding for continuing technology development so that we can make launching large observatories affordable. It was generally agreed that the cost of observatories is a large driver in the frequency of launches on an Ares V.

A significant amount of discussion centered around how to get the astronomical community interested in the Ares V as a platform for launching large observatories. The group discussed a number of options for poster sessions at upcoming conferences, such as organizing a session or symposium at the upcoming American Association for the Advancement of Science (AAAS). The possibility of creating models of the Ares V for display at the AAAS was also mentioned. The results of the workshop will be reported at the 59th International Astronautical Congress (IAC) in Scotland.

The Space Studies Board and the Aeronautics and Space Engineering Board of the National Research Council (NRC) are also studying the science opportunities enabled by NASA's Constellation system of launch vehicles and spacecraft. It was felt that we should ensure that the results of our workshop are communicated to them. To this end a formal report on the workshop will be presented to the committee at their third meeting in Boulder this June. A copy of the workshop report, which will be published as a NASA Conference Proceeding, will also be given to the committee.

As an outgrowth of the success of this workshop, a second workshop on Solar System Science enabled by an Ares V is being held in August 2008 at Ames Research Center. Two other workshops are being considered, namely, one on Earth Science missions enabled by an Ares V, and one on robotic/human servicing missions.

Agenda

Ares-V Astronomy Workshop			
		DAY ONE Sat., April 26th	
Time	**Dur. (min)**	**Description**	**Speakers & Discussion leaders**
8:00	30	Breakfast	
8:30	5	Logistics	Stephanie Langhoff
8:35	10	Welcome/objectives	Pete Worden
8:45	15	Introduction of participants	Stephanie Langhoff
Ares-V Capability			**Greg Sullivan**
9:00	30	FOUNDATIONAL TALK: Constellation Overview	Steve Cook
9:30	30	Discussion	
10:00	30	Ares V Overview	Phil Sumrall
10:30	30	Discussion	
11:00	15	Break	
11:15	30	Ares V Performance	Phil Sumrall
11:45	30	Discussion	
12:15	20	Lessons from HST: Maximizing the value of large investments	Frank Cepollina
12:35	20	Discussion	
12:55	60	Lunch	
Telescope Concepts/Missions			**Harley Thronson**
13:55	15	Emerging Pathways for the Single Aperture Far Infrared Telescope with an Ares V	Dan Lester
14:10	15	Discussion	
14:25	15	ATLAST: the Roadmap to an 8-m to 16-m UV/Optical Space Telescope	Marc Postman
14:40	15	Discussion	
14:55	15	Stellar Imager (SI): Viewing the UV/Optical Universe in High Definition	Ken Carpenter
15:10	15	Discussion	
15:25	15	Break	
15:40	15	Generation-X: a Mission Enabled by Ares V	Roger Brissenden
15:55	15	Discussion	
16:10	15	Submillimer Probe of the Evolution of Cosmic Structure (SPECS) Spectrometer enabled by Ares V	Stephen Rinehart
16:25	15	Discussion	
16:40	15	The Dark Ages Lunar Interferometer	Joe Lazio
16:55	15	Discussion	
17:10	15	Starshades in the Ares V	Tupper Hyde
17:25	15	Discussion	
17:40	30	Wine and cheese social	
18:10		Adjorn	
19:00		DINNER: Chef Chu's, 1067 N San Antonio Rd, Los Altos	

Agenda

		DAY TWO Sun., April 27th	
Time	Dur. (min)	Description	Speakers & Discussion leaders
8:00	30	Breakfast	
Technology challenges			**Kenneth Morris**
8:30	60	Panel Discussion-Strategic Trades and Questions	Session two speakers
9:30	20	Future space robotics and large optical systems	Tracey Espero
9:50	20	Discussion	
10:10	20	Future deployment systems and very large fairings	Chuck Lillie
10:30	20	Discussion	
10:50	15	Break	
11:05	20	Libration-Point and Lunar-Swingby Trajectories	Bobby Williams
11:25	20	Discussion	
11:45	15	TLYF Optical Testing of ARES V Large Optical Spacecraft: The LOTIS Collimator Option	Steve West
12:00	15	Discussion	
12:15	60	Lunch	
Breakout Sessions			
13:15	5	Introduction to Breakout Sessions	Stephanie Langhoff
13:20	90	(1) What breakthrough science can be done with an Ares V? (2) Payload development: Technological and environmental issues (3) Is there value in simplicity?	Chairs: 1-John Karcz; 2-Gary Martin; 3-Randy Correll/Phil Stahl
14:50	15	Break	
15:05	30	Reporting of breakout groups	Session Chairs
15:35	45	DISCUSSION: Research priorities-where do we go from here?	Pete Worden
16:20		Adjourn	

List of Participants

NAME	AFFILIATION	
Bailey, Samuel (Hop)	hbailey@as.arizona.edu	Univ. of Arizona
Baker, Craig	fcbaker@raytheon.com	Raytheon
Bell, Raymond	ray.bell@lmco.com	LMCO
Brissenden, Roger	rjb@head.cfa.harvard.edu	Smithsonian Astrophys. Obs.
Carpenter, Kenneth	kenneth.g.carpenter@nasa.gov	NASA Goddard
Cepollina, Frank	frank.j.cepollina@nasa.gov	NASA GSFC
Chivatero, Craig	craig.chivatero@lmco.com	LMCO
Cook, Steve	stephen.cook@nasa.gov	NASA MSFC
Content, David	david.a.content@nasa.gov	NASA GSFC
Correll, Randy	rcorrell@ball.com	Ball Aerospce
Creon, Levit	Creon.Levit@nasa.gov	NASA ARC
Crumbly, Chris	ccrumbly@ball.com	Ball Aerospace
Cuzner, Gregor	greg.cuzner@lmco.com	LMCO
Dailey, Dean	dean.dailey@ngc.com	NGC
Day, Dwayne	Dday@nas.edu	NRC
Dunham, David	niki.werkheiser@nasa.gov	Kinetx
Ennico, Kimberly	Kimberly.Ennico@nasa.gov	NASA ARC
Espero, Tracey	tracey.m.espero@boeing.com	Boeing
Gonzales, Andy	agonzales@arc.nasa.gov	NASA ARC
Horack, John	john.m.horack@nasa.gov	NASA MSFC
Hutchison, Sheldon	sheldon.b.hutchison@lmco.com	LMCO
Hyde, Tupper	tupper.hyde@nasa.gov	NASA GSFC
Karcz, John	jkarcz@arc.nasa.gov	NASA ARC
Langhoff, Stephanie	slanghoff@mail.arc.nasa.gov	NASA ARC
Lazio, Joe	joseph.lazio@nrl.navy.mil	NRL
Lee, Tim	Timothy.J.Lee@nasa.gov	NASA ARC
Lemke, Larry	llemke@mail.arc.nasa.gov	NASA ARC
Lester, Daniel	dfl@astro.as.utexas.edu	Univ. of Texas
Lewis, Brian	Brian.S.Lewis@aero.org	Aerospace Corp.
Lillie, Charles	chuck.lillie@ngc.com	Northrop Grumman
Luna, Phil	Phil.M.Luna@nasa.gov	NASA ARC

List of Participants

NAME	AFFILIATION	
Martin, Gary	gmartin@nasa.gov	NASA ARC
Miller, David	millerd@MIT.EDU	MIT
Morris, Bruce	Bruce.Morris@nasa.gov	NASA MSFC
Oegerle, William	william.r.oegerle@nasa.gov	NASA GSFC
Postman, Marc	postman@stsci.edu	STScI
Rinehart, Stephen	stephen.a.rinehart@nasa.gov	NASA GSFC
Schuresko, Dan	DS.comms@verizon.net	NRO/IMINT
Smith, Robert	rjs@astro.livjm.acuk	Astrophysics Research Inst.
Stahl, Philip	h.philip.stahl@nasa.gov	NASA MSFC
Sullivan, Greg	GPS@AOL.COM	NASA MSFC
Sumrall, Phil	john.p.sumrall@nasa.gov	NASA MSFC
Tenerelli, Dom	domenick.tenerelli@lmco.com	LMCO
Thronson, Harley	harley.a.thronson@nasa.gov	NASA GSFC
Tyson, Richard	richard.w.tyson@nasa.gov	NASA GSFC
West, Steve	swest@as.arizona.edu	Univ. of Arizona
Weston, Alan	alan.r.weston@nasa.gov	NASA ARC
Williams, Bobby	bobby.williams@kinetx.com	Kinetx
Worden, Pete	Simon.P.Worden@nasa.gov	NASA ARC
Yount, Bryan	bryan.c.yount@nasa.gov	NASA ARC

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[1]Stephanie Langhoff, [2]Dan Lester, [3]Harley Thronson, and [4]Randy Correll

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
[1]NASA Ames Research Center, Moffett Field, California
[2]Department of Astronomy, The University of Texas at Austin, Texas
[3]Astrophysics Division, NASA Goddard Space Flight Center, Greenbelt, Maryland
[4]Ball AeroSpace, Boulder, Colorado

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Point of Contact: Stephanie R. Langhoff, Ames Research Center, MS 241-20, Moffett Field, CA 94035-1000
(650) 604-6213, Stephanie.R.Langhoff@nasa.gov

14. ABSTRACT
The workshop was focused on three major themes: (1) How can elements of the Constellation program, and specifically, the planned Ares V heavy-launch vehicle, benefit the astronomical community by enabling the launch of telescopes that cannot be launched on existing vehicles, and how can the capabilities of an Ares V allow the astron my community to augment designs, achieve lower risk, and perhaps lower cost on these missions? (2) What are some of the telescope concepts that either can be significantly enhanced or enabled by an Ares V launch vehicle? What constraints do these mission concepts place on the payload environment of the Ares V? And (3) Technology challenges that need to be addressed for launching and servicing large observatories.

15. SUBJECT TERMS
Telescope concepts/missions, Ares V heavy launch vehicle, Large monolithic mirrors

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					Stephanie Langhoff
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